Transverse spin Effects in pp scattering and $Q\bar{Q}$ production

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Spin 2002

* Two-gluon exchange – common object in:
  - Elastic pp scattering
  - Diffractive $Q\bar{Q}$ production in pp & ep reactions

Two gluon exchange $\longleftrightarrow$ GPD (gluon)!

* Modell $\longrightarrow$ transverse spin effects in two-gluon coupling with proton.
  - $\to$ predictions for PP2PP experiment
  - $\to$ predictions for $Q\bar{Q}$ production in diffractive reactions

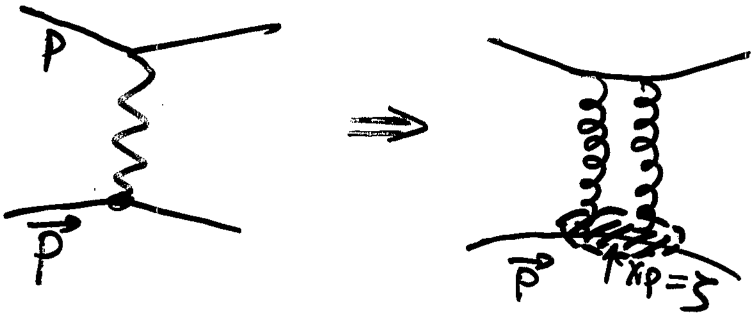
(Transverse asymmetry)

High energy hadron reactions

→ Pomeron exchange is predominated.

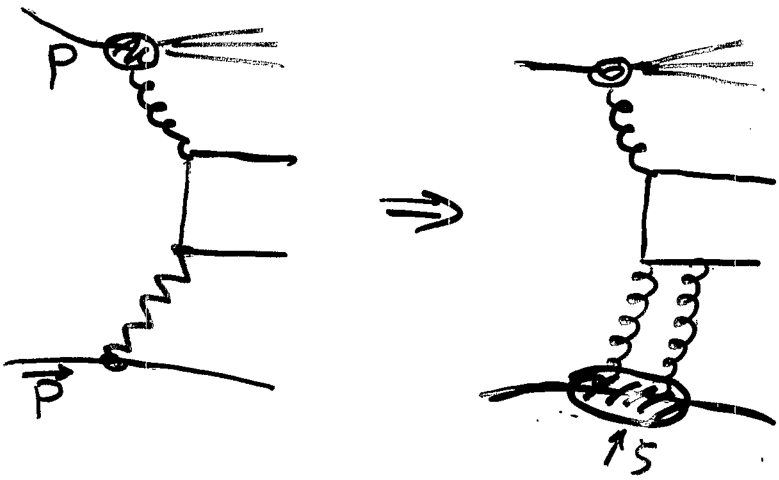
QCD Pomeron → 2 gluon exchange

⊛ (PP) elastic scattering



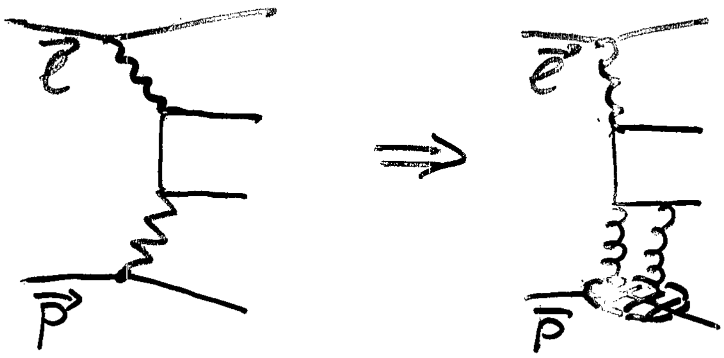
$x_P = \zeta \propto \frac{M^2}{s} \sim 0$

⊛ $Q\bar{Q}$ diffractive production in (PP)



x, ζ may be not small $\lesssim 0.1$

$Q\bar{Q}$ diffractive production in (eP)



x, ζ may be not small $\lesssim 0.$

The same gluon GPD at different

The two-gluon coupling with the proton has the following structures

$$
\begin{aligned}
V^{\alpha\beta}_{pgg}(p,t,x_P,l_\perp) &= B(t,x_P,l_\perp)(\gamma^\alpha p^\beta + \gamma^\beta p^\alpha) \\
&+ \frac{iK(t,x_P,l_\perp)}{2m}(p^\alpha \sigma^{\beta\gamma} r_\gamma + p^\beta \sigma^{\alpha\gamma} r_\gamma) \\
&+ \;.... \qquad (2)
\end{aligned}
$$

The structure proportional to $B(t,...)$ determines the spin-non-flip contribution. The term $\propto K(t,...)$ leads to the transverse spin-flip at the vertex.

The meson–proton helicity-non-flip and helicity-flip amplitudes can be written in terms of the functions $\tilde{B}$ and $\tilde{K}$ at small $x \sim$

1.2 Proton Two Gluon Coupling and Hadron Tensor

The hadronic tensor is given by

$$
\begin{aligned}
W^{\alpha\alpha';\beta\beta'}(s_p) = \sum_{spin\ s_f} &\bar{u}(p',s_f)V^{\alpha\alpha'}_{pgg}(p,t,x_P,l)u(p,s_p) \\
&\bar{u}(p,s_p)V^{\beta\beta'\,+}_{pgg}(p,t,x_P,l')u(p',s_f) \qquad (4)
\end{aligned}
$$

and is determined by a trace similar to the lepton case. The spin–average and spin–dependent hadron tensors

$$
W^{\alpha\alpha';\beta\beta'}(\pm) = \frac{1}{2}(W^{\alpha\alpha';\beta\beta'}(+s_p) \pm W^{\alpha\alpha';\beta\beta'}(-s_p)). \qquad (5)
$$

s_p- arbitrary spin vector (transversely or longitudinally polarized target). In the last case, the contribution of D structure should be considered. For the leading term of spin- average structure $W(+)$ for the ansatz

$$W^{\alpha\alpha';\beta\beta'}(+) = 16 p^\alpha p^{\alpha'} p^\beta p^{\beta'} (|B|^2 + \frac{|t|}{m^2}|K|^2). \tag{6}$$

The obtained equation for the spin-average tensor coincides in form with the cross section of the proton off the spinless particle (meson or unpolarized proton e.g.).

The spin-dependent part of the hadron tensor can be written as

$$W^{\alpha\alpha';\beta\beta'}(-) = S_0^{\alpha\alpha';\beta\beta'} + S_r^{\alpha\alpha';\beta\beta'} + A_t^{\alpha\alpha';\beta\beta'}. \tag{7}$$

The functions S are symmetric in α, α' and β, β' indices

$$S_0^{\alpha\alpha';\beta\beta'} = 8i\frac{BK^* - B^*K}{m} p^\beta p^{\beta'} \Gamma^{\alpha\alpha'} \tag{8}$$

A Goloskokov

and

$$\begin{aligned} S_r^{\alpha\alpha';\beta\beta'} &= 2i\frac{B^*K}{m}\left(p^\alpha (r_P)^{\alpha'} + p^{\alpha'}(r_P)^\alpha\right)\Gamma^{\beta\beta'} \\ &- 2i\frac{BK^*}{m}\left(p^\beta (r_P)^{\beta'} + p^{\beta'}(r_P)^\beta\right)\Gamma^{\alpha\alpha'} \end{aligned} \tag{9}$$

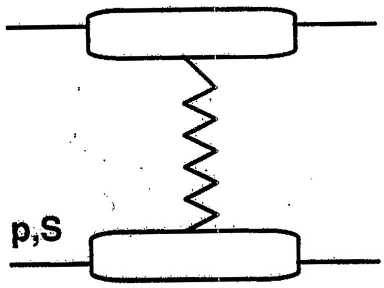
Here

$$\Gamma^{\alpha\alpha'} = p^\alpha \epsilon^{\alpha'\gamma\delta\rho} p_\gamma (r_P)_\delta (s_p)_\rho + p^{\alpha'} \epsilon^{\alpha\gamma\delta\rho} p_\gamma (r_P)_\delta (s_p)_\rho \tag{10}$$

The function A_t is asymmetric in indices

$$\begin{aligned} A_t^{\alpha\alpha';\beta\beta'} &= 2i|t|\frac{B^*K}{m}\left[p^\alpha p^\beta \epsilon^{\alpha'\beta'\delta\rho} p_\delta (s_p)_\rho + p^\alpha p^{\beta'} \epsilon^{\alpha'\beta\delta\rho} p_\delta (s_p)_\rho \right. \\ &+ \left. p^{\alpha'} p^\beta \epsilon^{\alpha\beta'\delta\rho} p_\delta (s_p)_\rho + p^{\alpha'} p^{\beta'} \epsilon^{\alpha\beta\delta\rho} p_\delta (s_p)_\rho\right] \end{aligned} \tag{11}$$

Note that these forms are general and can be used for different polarization vectors of the proton. For longitudinal proton polarization, the structure D should be considered in addition.



m^2/s integrated over momentum $l_\perp$

$$F_{++}(s,t) = is[\tilde{B}(t)]f(t); \;\; F_{+-}(s,t) = is\frac{\sqrt{|t|}}{m}\tilde{K}(t)f(t), \qquad (3)$$

where $f(t)$ is determined by the Pomeron coupling with meson.

The models

S.V. Goloskokov, P. Kroll, Phys. Rev. D **60**, 014019 (1999)

S.V. Goloskokov, S.P. Kuleshov, O.V. Selyugin, Z. Phys. **C50**, 455 (1991)

predict single spin transverse asymmetry

$$A_T \sim \frac{2\ \mathrm{Im}[\tilde{B}\,\tilde{K}^*]}{|\tilde{B}|^2} \qquad (4)$$

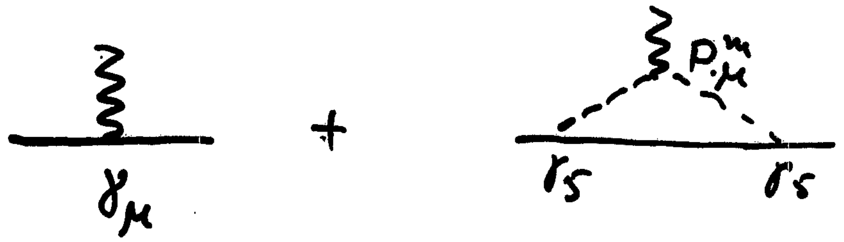
of about 10% for $|t| \sim 3\mathrm{GeV}^2$. It has been found in that the ratio $|\tilde{K}|/|\tilde{B}| \sim 0.1$ and has a weak energy dependence (weak x dependence)

The weak energy dependence of spin asymmetries in exclusive reactions is not in contradiction with the experiment. Predictions for PP2PP experiments at RHIC:

*) Goloskokov, Kuleshov, Selyugin

Large-distance effects in hadron stat

1). Gluons from the Pomeron can interect with the meson cloud of the proton as well as with the proton core: $\sim \underline{\underline{\sigma^{\mu\nu}\cdot\Delta^{\nu}\cdot\tilde{A}}}$



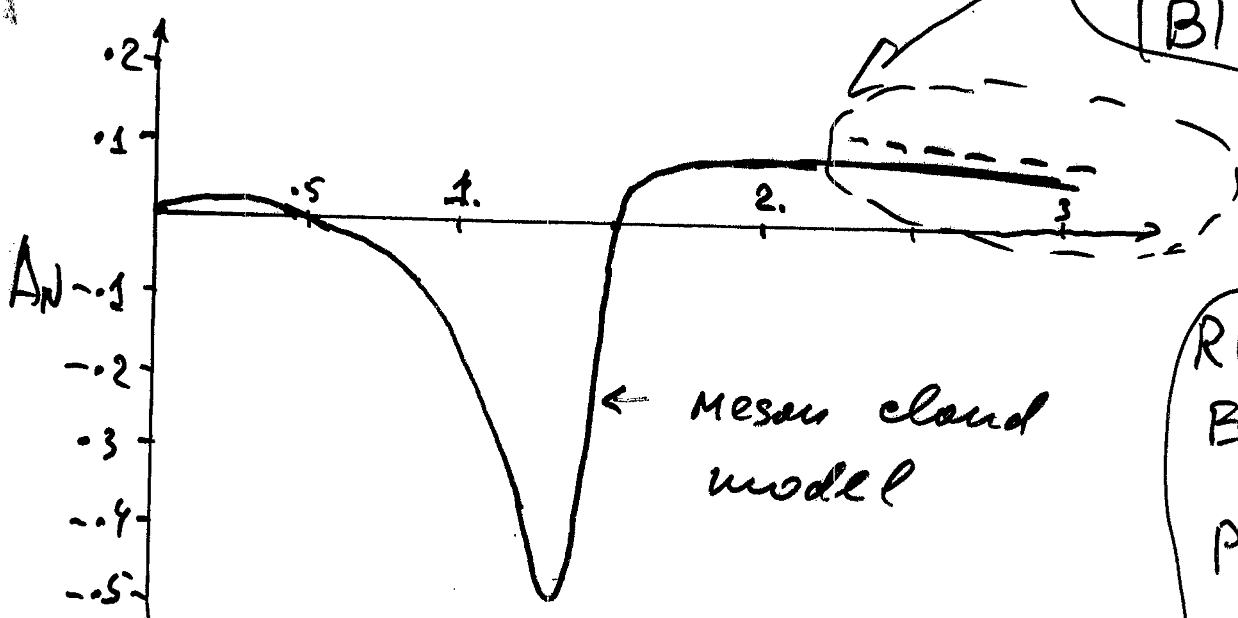
$\rightarrow \gamma_\mu \cdot B + P_\mu \cdot K$

Spin-flip effects in Pomeron coupling.

$$d\sigma \sim |B(t)|^2 + |t|/m^2 |K|^2$$

$$A_N \sim \frac{2 \cdot \mathrm{Im}(B \cdot K^*) \cdot \sqrt{|t|}}{d\sigma}$$

$\frac{|K|}{|B|} \sim 0{,}1\,\mathrm{GeV}^{-1}$



RHIC Energies PP2PP Experiment

Similar ratio of $\frac{|A|}{}\sim 0.1$ in qd-model (Akchurin Goloskokov Selyugin 99')

S. Goloskokov, S. Kuleshov, O. Selyugin

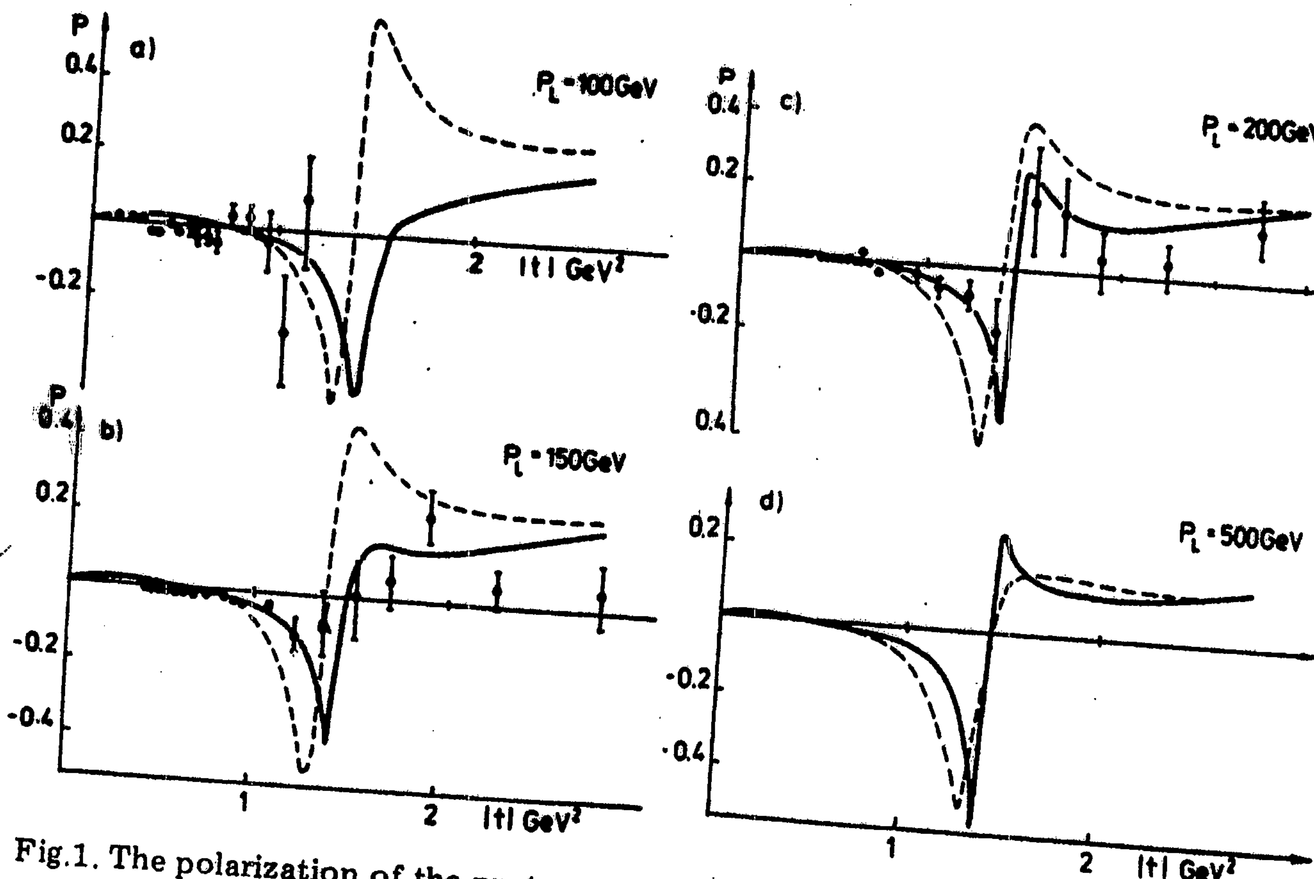
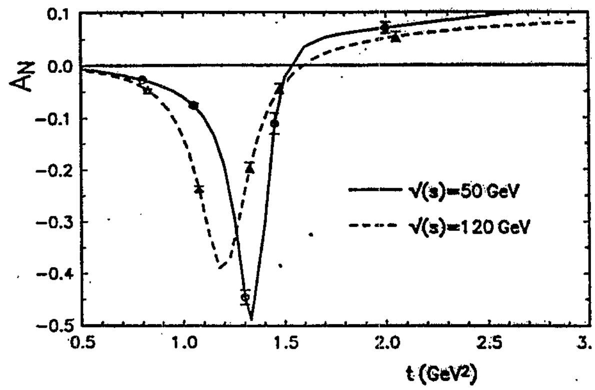


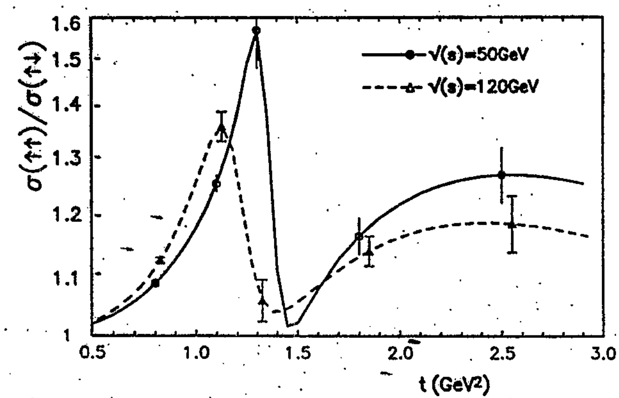
Fig.1. The polarization of the proton-proton (solid curves) and the proton-antiproton (dashed currves) scattering a) 100 GeV, b) 150 GeV, c) 200 GeV, d) 500 GeV.

M.C.M → PP2PP

stable

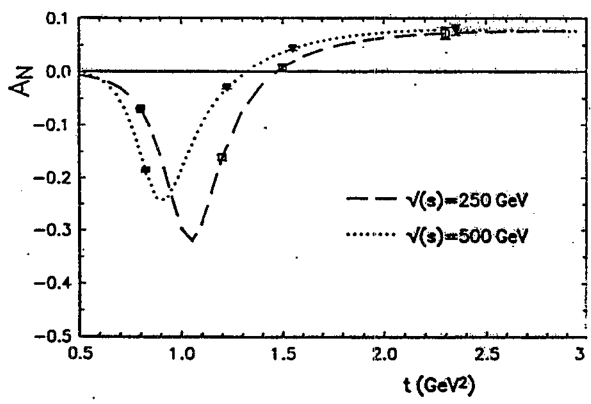
stable

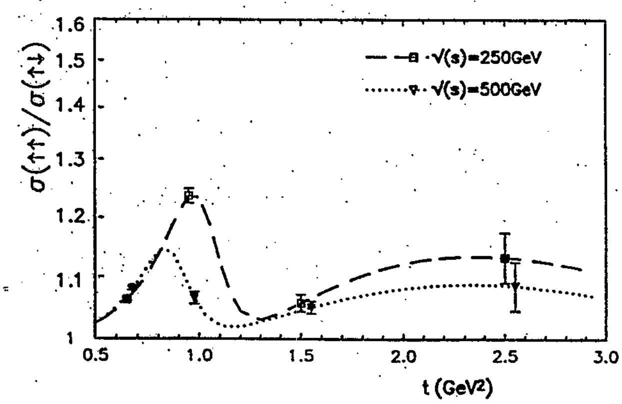




$$\boxed{A_N \propto \mathrm{Im}(B \cdot K^*) \sim \mathrm{Re}B \cdot \mathrm{Im}K}$$

$\mathrm{Im}\, B(t) = 0$ → diffraction minimum.

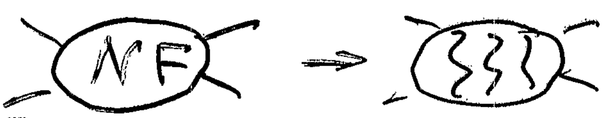




A_N $\sigma(\uparrow\uparrow)/\sigma(\uparrow\downarrow)$

Model prediction at RHIC energies (for PP2PP experiment)

N. Akchurin, S. Goloskokov, O. Selyugin, 98-99

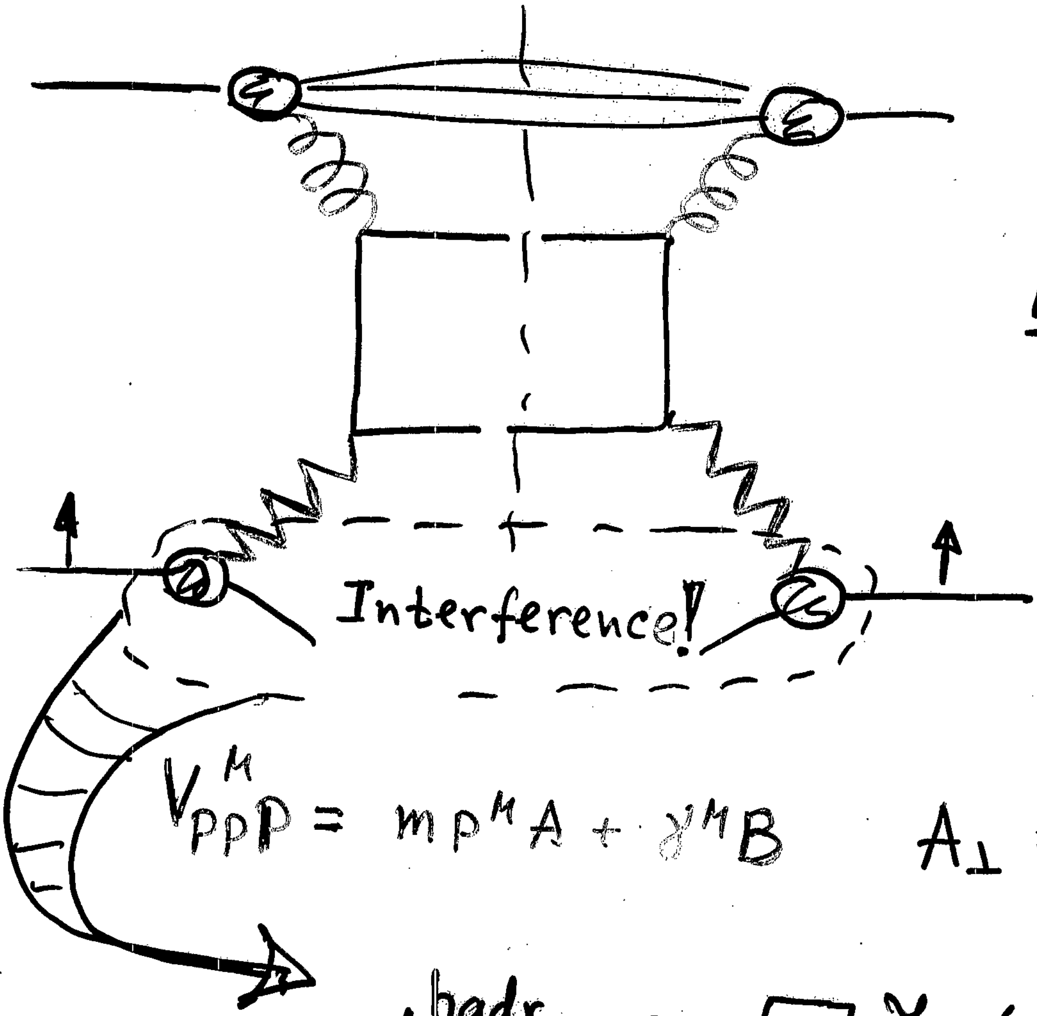


Pomeron rescatterings in eikonal form.

Flip

Single spin asymmetry in diffractive $Q\bar{Q}$ production

Goloskokov 95'-96'



PP reaction

$$\begin{cases} \sigma = \sigma(\uparrow) + \sigma(\downarrow) \\ \Delta\sigma = \sigma(\uparrow) - \sigma(\downarrow) \end{cases}$$

$$V^{\mu}_{ppP} = m p^{\mu} A + \gamma^{\mu} B \qquad A_{\perp} = \frac{\Delta\sigma}{\sigma} \propto A_{\perp}^{hadr.}$$

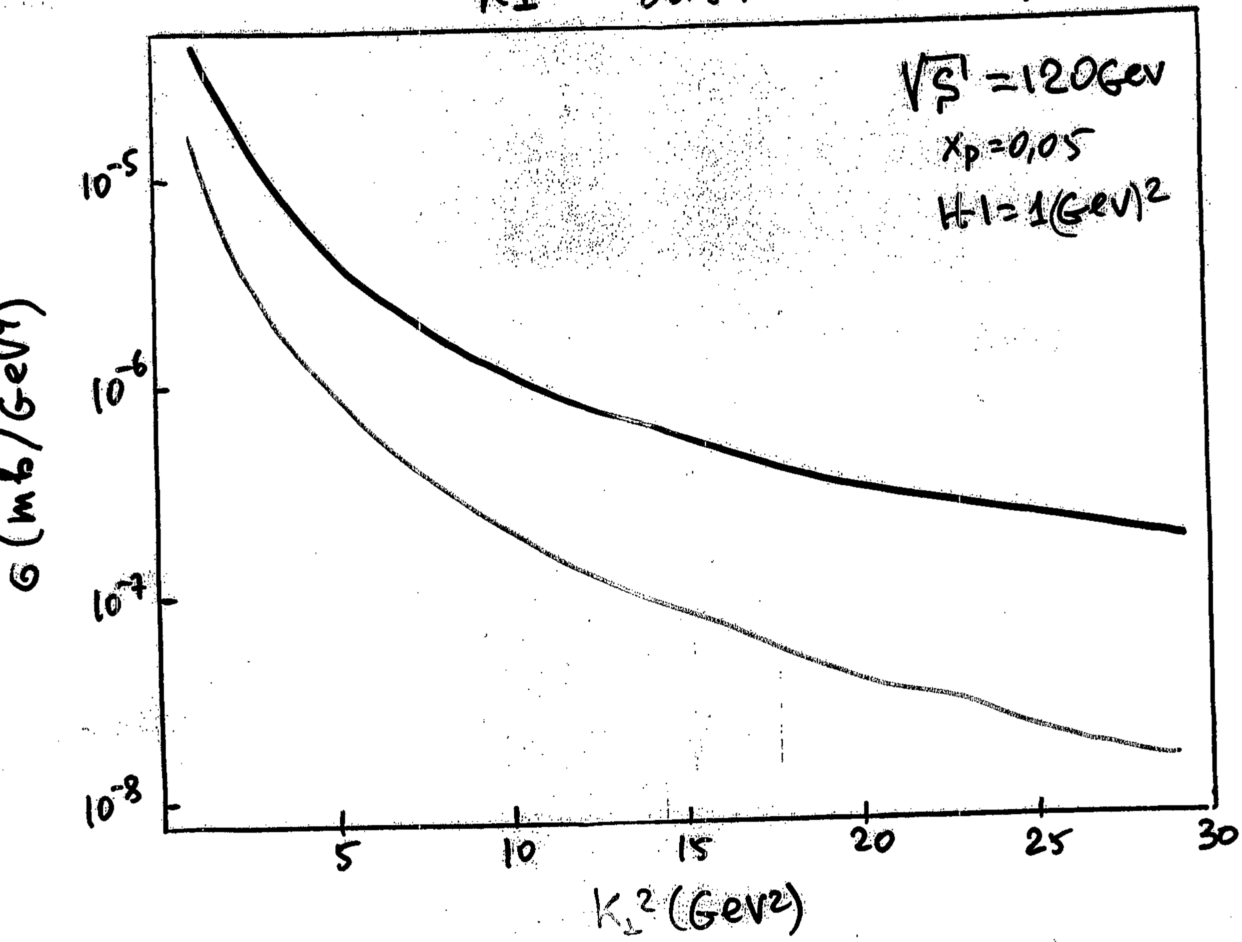
$$A_{\perp}^{hadr} \simeq \frac{2m\sqrt{|t|}\,\Im m(AB^{*})}{|B|^{2}}$$

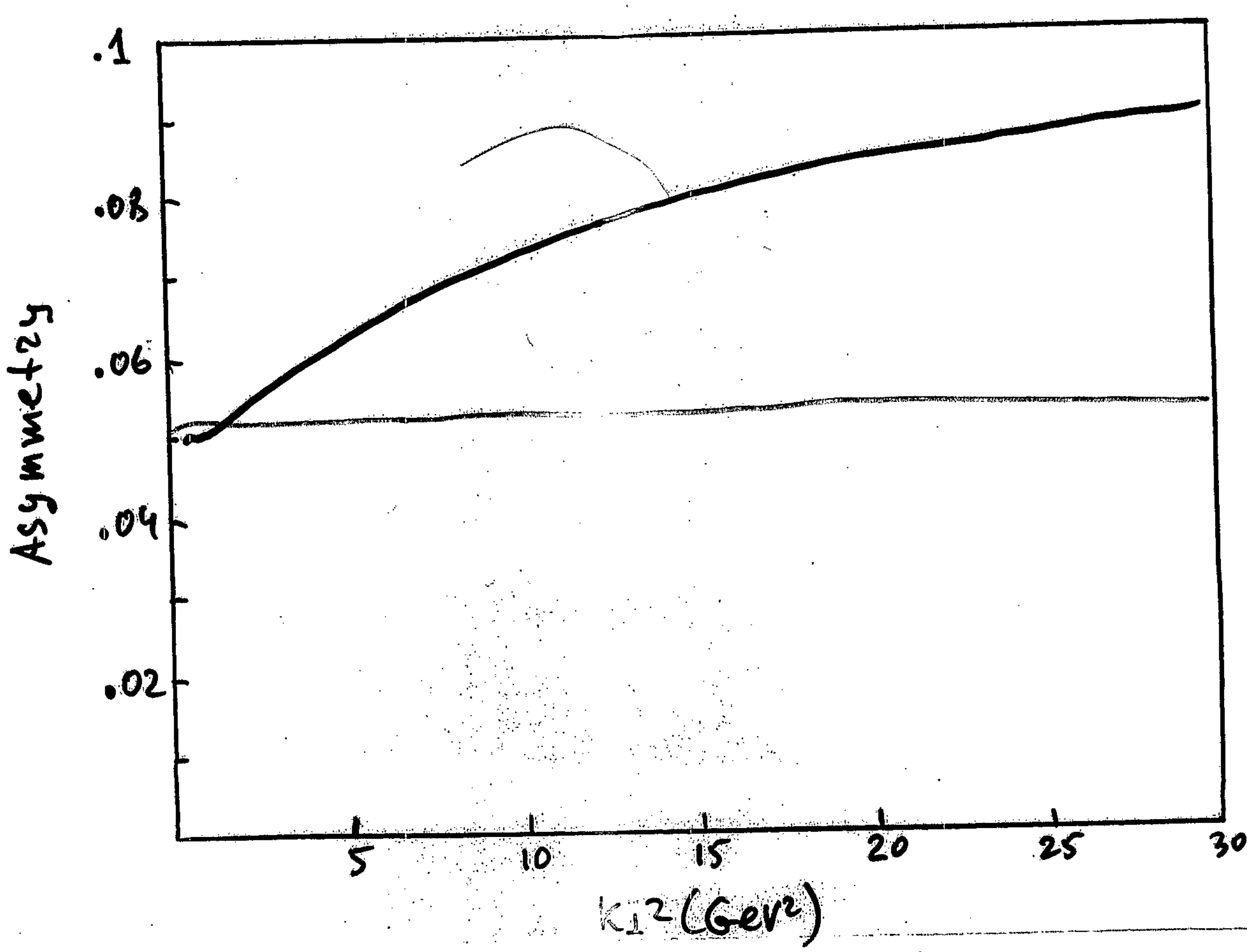
$A_{\perp}^{hadr} \sim 10-15\%$ at $|t| \sim 1\,GeV^2$

From elastic pp scattering

$\Rightarrow$ the same value: $A_{\perp}^{hadr} \sim 10\%$

LHC (fixed target)
$K_\perp^2$ distribution:



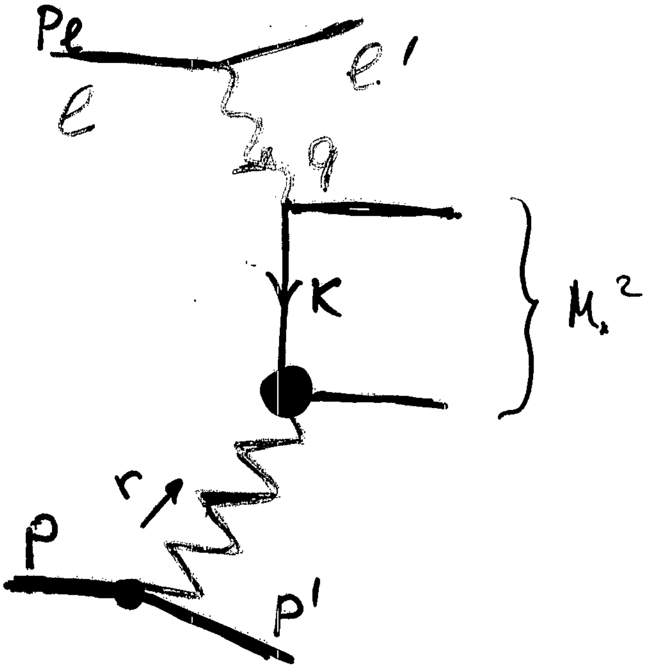


— standard vertex

* ep deep inelastic diffractive scattering

$Q\bar{Q}$ contribution:

Goloskokov 96 - 2002



H1, ZEUS experiments at HERA

COMPASS (CERN)

Erhic

variables:

$$Q^2 = -q^2, \quad t = r^2 = (p-p')^2$$

$$y = \frac{pq}{P_e P}, \quad x = \frac{Q^2}{2pq}, \quad x_p = \frac{q(p-p')}{pq}, \quad \beta = \frac{x}{x_p}$$

$$\beta \simeq \frac{Q^2}{Q^2 + M_x^2}$$

($l_x^2 \propto x_p \cdot y \cdot S$) x_p is not fixed - usually

As a result, the spin-average and spin-dependent cross section can be written in the form

$$\frac{d^5\sigma(\pm)}{dQ^2dydx_pdtdk_\perp^2}=\left(\frac{(2-2y+y^2)}{(2-y)}\right)\frac{C(x_P,Q^2)\,N(\pm)}{\sqrt{1-4(k_\perp^2+m_q^2)/M_X^2}}. \qquad (35)$$

Here $C(x_P,Q^2)$ is a normalization function which is common for the spin average and spin dependent cross section; $N(\pm)$ is determined by a sum of graphs integrated over the gluon momenta l and l'

$$N(\pm)=\int\frac{d^2l_\perp d^2l'_\perp(l_\perp^2+\vec{l}_\perp\vec{r}_\perp)\,((l'_\perp)^2+\vec{l'}_\perp\vec{r}_\perp)\;D^{\pm}(t,Q^2,l_\perp,l'_\perp,k_\perp)}{(l_\perp^2+\lambda^2)((\vec{l}_\perp+\vec{r}_\perp)^2+\lambda^2)(l'^2_\perp+\lambda^2)((\vec{l'}_\perp+\vec{r}_\perp)^2+\lambda^2)}.$$

- The $D^{\pm}$ function here are traces over the quark loops of the graphs convoluted with the spin average and spin-dependent tensors.

- Considerable cancellation between the planar and nonplanar contribution of the graphs.

- In the numerator the terms proportional to the gluon momenta $l_\perp$ and $l'_\perp$ as in the case of vector meson production. $(l_\perp^2+l_\perp r_\perp)$

We write the analytic forms of the graph contribution to the cross sections in the limit $\beta\to 0$. The numerical calculation will be fulfiled for arbitrary β. The contribution of the sum of the graphs to the D^+ function for Region I can be written in the form

$$D_I^+=\frac{Q^2\left(|B|^2+|t|/m^2|K|^2\right)\left((k_\perp+r_\perp)^2+m_q^2\right)}{\left(k_\perp^2+m_q^2\right)\left((k_\perp-l_\perp)^2+m_q^2\right)\left((k_\perp-l'_\perp)^2+m_q^2\right)}. \qquad (36)$$

This function contains a product of the off-mass-spell quark propagators in the graphs. We see that the quark virtuality here is quite different as compared to the vector meson case. We have no the terms proportional to Q^2.

This will change the scale in gluon structure functions. Really, l and l' smaller than $k_\perp^2$ and the contribution of $D^p(+)$ to $N(+)$ is about

$$N^p(+) \sim \frac{\left(|\tilde{B}|^2 + |t|/m^2|\tilde{K}|^2\right)\left((k_\perp + r_\perp)^2 + m_q^2\right)}{\left(k_\perp^2 + m_q^2\right)^3} \tag{37}$$

with

$$\tilde{B} \sim \int_0^{l_\perp^2 < k_0^2} \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{r}_\perp)}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{r}_\perp)^2 + \lambda^2)} B(t, l_\perp^2, x_P, ...) = \mathcal{F}^g_{xP}(x_P, t, k_0^2) \tag{38}$$

and

$$\tilde{K} \sim \int_0^{l_\perp^2 < k_0^2} \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{r}_\perp)}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{r}_\perp)^2 + \lambda^2)} K(t, l_\perp^2, x_P, ...) = \mathcal{K}^g_{xP}(x_P, t, k_0^2) \tag{39}$$

with $k_0^2 \sim k_\perp^2 + m_q^2$. For nonzero β this scale is changed to $k_0^2 \sim \frac{k_\perp^2 + m_q^2}{1-\beta}$.

- The gluon structure functions are determined by the same integrals as in (23) but on a different scale.

For Region II, only the first planar graph of contributes. The graphs here have lines with large quark virtuality. Propagators of these lines become pointlike. As a result, the contribution to the cross section for Region II has different Q^2 and k^2 dependence with respect to Region I.

$$D_{II}^+ = \frac{2(1-y)\left(|B|^2 + |t|/m^2|K|^2\right)}{(2 - 2y + y^2)\left((k_\perp + r_\perp)^2 + m_q^2\right)}. \tag{40}$$

The ratio of the cross sections for Regions I and II. The ratio is growing with k^2. We find that the integration region II is essential of the function $N(-)$

$$N(-) = \sqrt{\frac{|t|}{m^2}}\left(\tilde{B}\tilde{K}^* + \tilde{B}^*\tilde{K}\right)[\frac{(\vec{Q}\vec{S}_\perp)}{m}\Pi_Q^{(-)}(t, k_\perp^2, Q^2) + \frac{(\vec{k}_\perp\vec{S}_\perp)}{m}\Pi_k^{(-)}(t, k_\perp^2, Q^2)]. \qquad (42)$$

The second term cannot be found in the vector meson production, because we should integrate there over $d^2k_\perp$.

5 Predictions for $Q\bar{Q}$ Leptoproduction

We consider only the asymmetry $A_{lT} = \sigma(-)/\sigma(+)$.
The same parameterizations of SPD.
The asymmetry is approximately proportional to the ratio of polarized and spin–average gluon distribution functions

$$A_{LT}^{Q\bar{Q}} \sim C^{Q\bar{Q}} \frac{\mathcal{K}_\zeta^g(\zeta)}{\mathcal{F}_\zeta^g(\zeta)} \quad \text{with } \zeta = x_P \text{ and } |\tilde{K}|/|\tilde{B}| \sim 0.1 \qquad (43)$$

The spin-dependent contribution has two terms proportional to the scalar products $\vec{k}_\perp\vec{S}_\perp$ and $\vec{Q}\vec{S}_\perp$.

The $\vec{k}_\perp\vec{S}_\perp$ term for the case when the transverse jet momentum $\vec{k}_\perp$ is parallel to the target polarization $\vec{S}_\perp$.

- It is necessary to distinguish experimentally the quark and antiquark jets.
- The transverse momentum of a quark and an antiquark are opposite in sign. If we do not separate events with $\vec{k}_\perp$ for the quark jet e.g., the asymmetry will be zero.
- Can be realized by the charge of the leading particles in the jet which should be connected in charge with the quark produced in photon-gluon fusion.

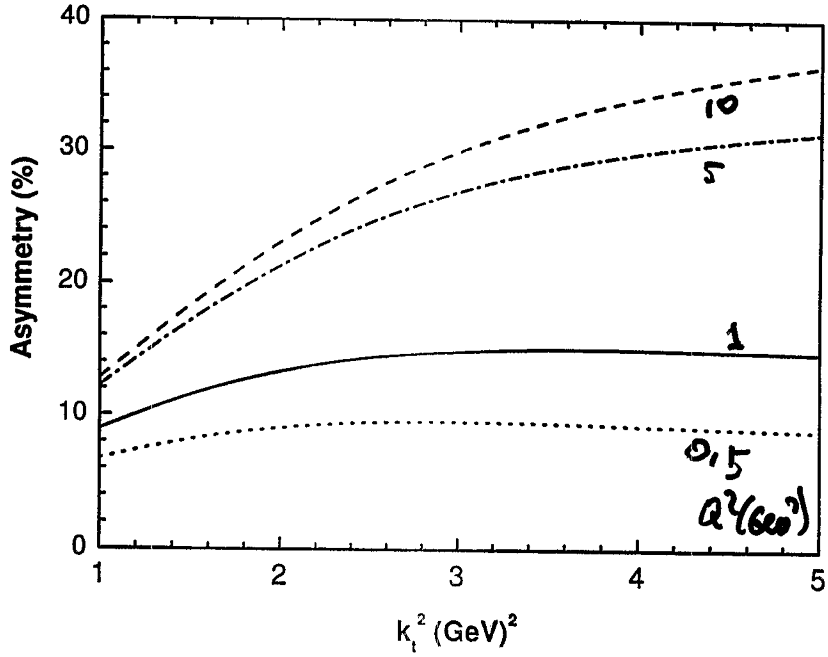


Figure 2: The A_{lT}^{k} asymmetry in diffractive light $Q\bar{Q}$ production at $\sqrt{s} = 20$GeV for $x_P = 0.1$, $y = 0.5$, $|t| = 0.3$GeV^2: dotted line-for $Q^2 = 0.5$GeV^2; solid line-for $Q^2 = 0.5$GeV^2; dot-dashed line-for $Q^2 = 5$GeV^2; dashed line-for $Q^2 = 10$GeV^2.

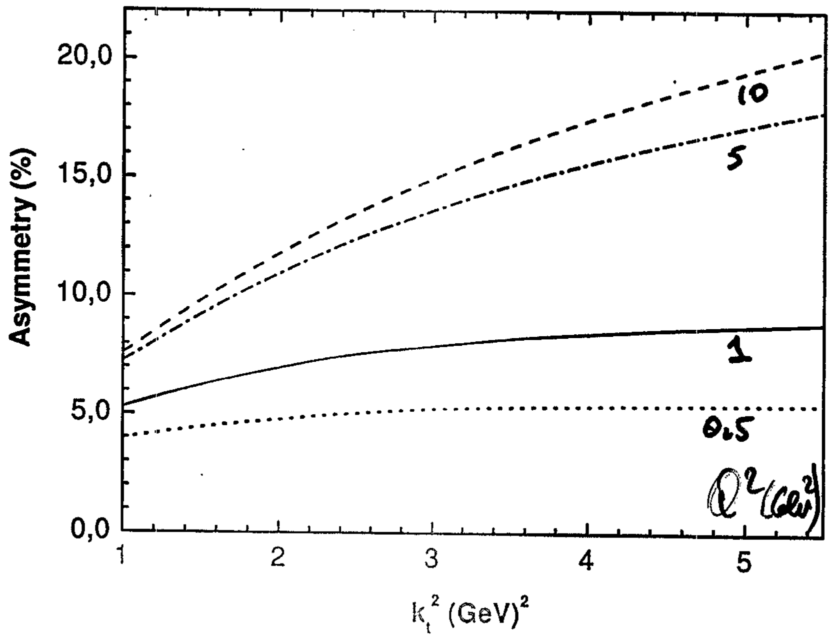


Figure 3: The A_{lT}^{k} asymmetry in diffractive heavy $Q\bar{Q}$ production at $\sqrt{s} = 20$GeV for $x_P = 0.1$, $y = 0.5$, $|t| = 0.3$GeV^2: dotted line-for $Q^2 = 0.5$GeV^2; solid line-for $Q^2 = 0.5$GeV^2; dot-dashed line-for $Q^2 = 5$GeV^2; dashed line-for $Q^2 = 10$GeV^2.

Conclusion

* Same polarized gluon distribution $\mathcal{K}(x,\xi)$

$\Downarrow$

Transverse spin effects in elastic pp and diffractive $Q\bar{Q}$ production

* Modell for $\mathcal{K}$ – non-vanished spin effects at small x

Predictions:

→ Large $A_\perp$ asymmetry in $P\vec{P}$ near diffract[ion] minimum.
Direct information on energy dependence of $\mathrm{Im}\,\mathcal{K}$ can be obtained

RHIC PP2PP

→ Large $A_\perp$ asymmetry in $Q\bar{Q}$ production $(p\vec{P})$

RHIC ? diffractio[n]

→ Large $A_{\ell T}$ asymmetry in diffractive $Q\bar{Q}$ production $(\vec{\ell}\vec{P})$

COMPASS, eRHIC

Information on polarized gluon distribution $\mathcal{K}$ can be obtained!